

**USACE New York Districts Application of the USACE TABS-MD 2-D hydrodynamic model code, RMA-2 (Resource Management Associates) to design the regrading plan for the proposed 30 acre intertidal marsh in Lincoln Park, Jersey City, NJ**

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Lincoln Park is an urban park 5 miles west of Manhattan, located on the east banks of the Hackensack River in Jersey City, NJ. The New Jersey Department of Environmental Protection approached the New York in 1998 as an interested local sponsor for a Section 1135 Ecosystem Restoration Project at the 90 acre parcel of land, currently dominated by the invasive species, *Phragmites australis*, hereafter referred to as *phragmites*. A project has been proposed to transform a 30 acre parcel of the existing 90-acre parcel of land into an intertidal wetland dominated by *spartina alterniflora*, which offers more ecological diversity than *phragmites*. Improving the tidal circulation of an existing 9-acre pond was a secondary project goal.

Historically, the project area functioned as a salt marsh, dominated by native salt marsh species, including *spartina alterniflora*, and the upland freshwater system was dominated by Atlantic white cedar. Following the timber harvesting of the cedar, in 1914, a concrete bulkhead was built to stabilize the Hackensack River as part of a proposed park building project that was never completed. Dredge material associated with the construction of the Hackensack River navigation channel was deposited on the site in the early part of the 20<sup>th</sup> century, followed by construction debris a few decades later. After the fill placement and the bulkhead construction, the tidal connection to the site became severely restricted. The created prime conditions were set up for *phragmites* to invade. *Spartina alterniflora* can be re-established at the site by reconnecting the tidal hydrodynamics throughout the site. The method proposed to accomplish this involves removing the *phragmites* and lowering the grade to elevations similar to a reference *spartina alterniflora* patch found adjacent to the site and the Hackensack River. A network of tidal creeks would be necessary to convey the tide throughout the proposed 30-acre intertidal wetland.

### **Existing Hydrology and Hydraulics**

The existing hydrology, surface water and tidal influences had to be evaluated first. On the east boundary of the project site is a 9-acre lake. All the storm water runoff from the 260-acre park is filtered into this lake. This lake is connected to the Hackensack River via a 3 ft diameter culvert, partially filled with silt. Tide gages were installed throughout the site during the summer of 2001. Refer to Figure 1 for the aerial view of the site, and the tide gage locations. The lake has an average tidal range of 0.5 ft, compared to the 5.28 ft tide range in the Hackensack River. Table 1 summarizes the tide gage results.



Figure 1: Location of Tide Gages

Table 1: Summary of Water Level Recorder Data and Rainfall at Lincoln Park Restoration Site

<b>Gage Period</b>	<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>	<b>E</b>	<b>F</b>
<b>Description</b>	east lake	west lake	creek	north of path	south of path	River
Start of Record	6/7/2001	6/26/2001	6/4/2001	7/25/2001	7/19/2001	6/8/2001
End of Record	7/19/2001	7/19/2001	7/25/2001	8/16/2001	8/16/2001	7/19/2001
East NAD 83 ft	606080	605807	604309	604387	604290	603983
North NAD 83 ft	690070	690461	690440	691119	691134	690359
<i>Water Level Statistics - in ft NGVD 1929</i>						
minimum	2.1	1.1	3.1	4.0	3.2	-2.7
mean	2.2	1.5	3.3	4.2	4.0	1.0
maximum	2.5	2.0	5.2	4.4	4.7	4.4
total rainfall during gage record (inches)	4.38	1.93	4.80	1.44	1.85	4.38

Tidal datums were computed for the Hackensack River tide gage. Not only was this gage in close proximity to the referenced wetland, this gage would also serve as the boundary condition for the hydrodynamic model that was used to design the tidal creek layouts. Figure 2 illustrate the results from bio-benchmarking *spartina alterniflora* and *Phragmites*, coupled with the tidal datum's computed from the river tide gage. The elevation ranges at which these plants currently grow indicate the duration of tidal flooding that is necessary for their survival. A target regrading range was established which was used for the conceptual designs and preliminary cost estimates. The duration of flooding was computed for existing *spartina alterniflora* (Table 2), and the hydrodynamic model results could verify that all the locations where *spartina alterniflora* was proposed, the duration of flooding would be in the same range as the existing *spartina alterniflora*. Existing cross-sections of reference creeks in Hackensack River that connect wetlands of similar tidal prisms were also used in the conceptual plan layouts.

## Lincoln Park Ecosystem Restoration

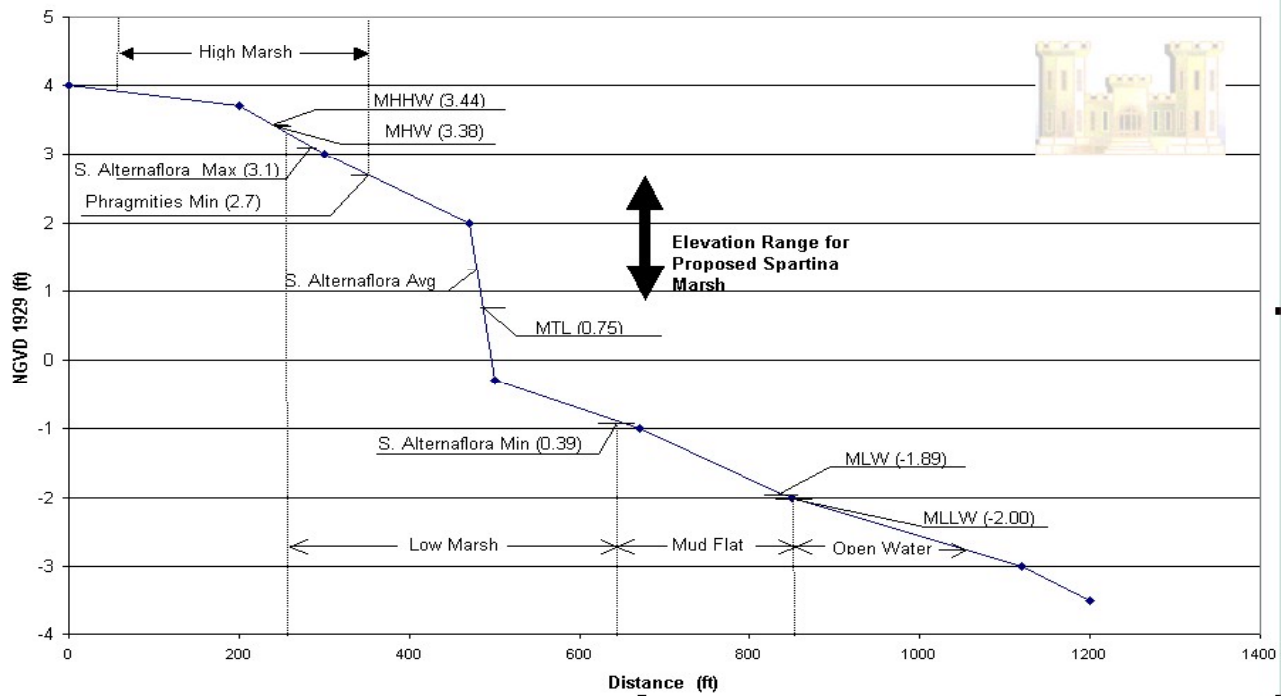


Figure 2: Bio-Benchmark Design Plot

Table 2: Summary of Duration of Flooding - Existing and Proposed Marsh

	Elevations in ft NGVD29	Duration of Flooding for Average Tide Cycle**	
		percent	Hours
<i>spartina alterniflora</i> min. elevation	0.1	69%	6.5
<i>spartina alterniflora</i> avg. elevation	1.7	40%	4.5
<i>spartina alterniflora</i> max. elevation	3.1	12%	2.1
<i>Phragmites australis</i> min. elevation	2.7	24%	2.9

\*\* Based on Mean Low Water and Mean High Water Datums computed at the River Gage, Mean Tide Level at 0.75 ft and Tide Range of 5.28 ft

Seven conceptual plans were evaluated. First, all areas in the site with existing grades less than 10 ft NGVD1929 were identified, as they would represent the least amount cut/fill volumes. The first plan incorporated the those lower grade locations that were continuous, and it kept all existing recreational paths through the site, with culverts planned to convey the tide to inland areas. The Project Delivery Team (PDT) decided that it was less of a priority to leave in the recreational paths, so they were removed in the next alternative. Re-connecting the lake to a tidal creek surfaced as an alternative design feature. As the PDT evaluated alternatives, preliminary cost estimates were generated, and the ecological functional capacity units were assigned. Figure 3 represents all the features of the selected alternative.

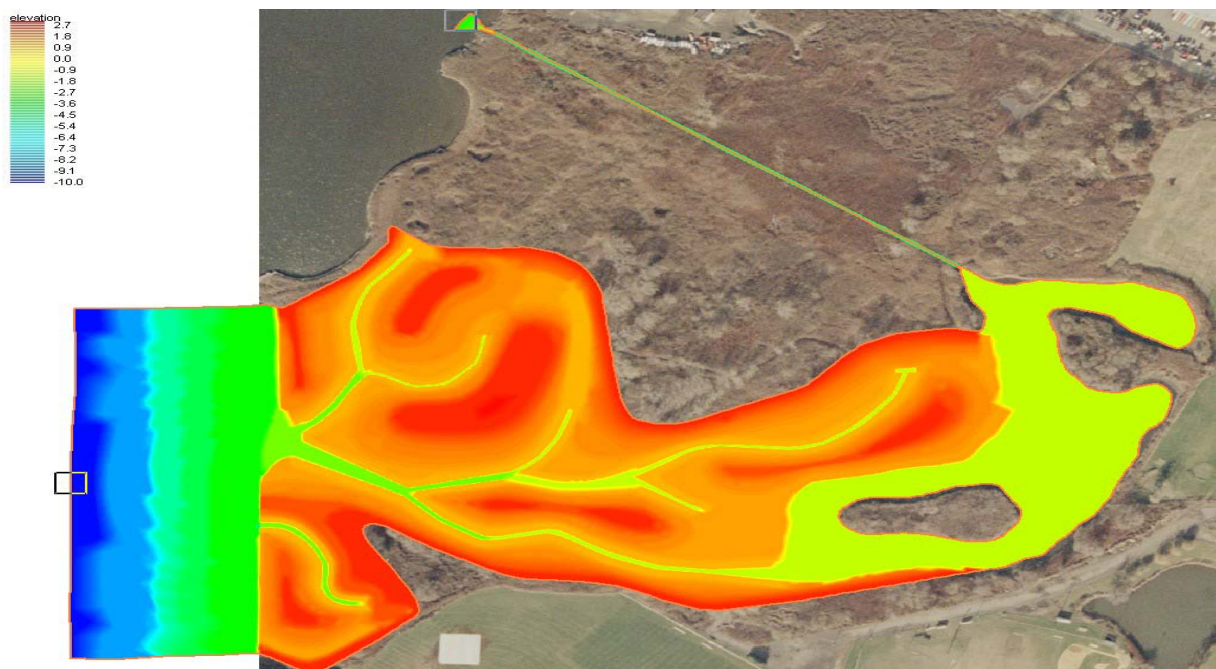


Figure 3: Proposed Elevations for the selected alternative, and the Model Domain

### Hydrodynamic Model Description

A hydrodynamic model was run to optimize the chosen conceptual plan (Figure 3). The model allowed PDT to evaluate the duration of flooding in the proposed intertidal wetland, the tidal flushing in the pond, and the maximum velocities in the creek channels to determine if sedimentation or scouring would occur. The duration of flooding in the proposed intertidal marsh was validated against the current range of flooding in addition to the plant specific criteria for *Spartina Alterniflora*, which requires inundation from 12 % to 69 % of the time.

The US Army Corps of Engineers TABS-MD two-dimensional (2-D) hydraulic model code, RMA-2 (Resource Management Associates) was the tool used to validate the hydrology design for the project. RMA-2 numerically solves the depth-averaged form of the full Navier-Stokes equations. It is one of the models being applied in the ongoing USACE New York/New Jersey Harbor Deepening Study. The model is capable of simulating the complex non-linear interactions of Lincoln Park's existing hydraulic features in response to tides. After being calibrated to the existing conditions, the model could then be used to predict the hydraulic behavior of proposed regrading plans of the wetland. The model determines the water levels and horizontal velocity vectors in two directions in the channels and intertidal zones of the wetland. The model domain is illustrated in Figure 2. The (2-D) depth-averaged grid portrays most of domain, with the exception of the one dimensional elements that replicate the buried 3 ft diameter culvert that currently connects the Hackensack River to the northwestern portion of the lake. The input data consisted of the following:

1. Geometry data for the model was created based on looking at the existing topography and determining proposed regraded elevations with considerable attention paid to the biobenchmarks. Proposed elevations were mapped to the mesh by selecting different material properties and manually assigning the elevation values.
2. Boundary conditions were determined by the tidal datums calculated in the Hackensack River. It was determined that the tidal boundary condition was orders of magnitude greater than the fluvial events and thus only the tidal boundary condition was used. Refer to Table 3 for the tidal datums that generated the boundary conditions.
3. The hydrodynamic modeling parameters required for RMA2 are presented in Table 4 and 5. Refer to Figure 4 for the marsh material type designation.

Table 3: Tidal Datums used for the Dynamic Boundary Condition

Mean High Water (ft)*	3.39
Mean Tide Level (ft)*	0.75
Mean Low Water (ft)*	-1.89
Tide Range (ft)	5.28
Tidal Period used for Boundary Condition**	12 hours

\* referenced to NGVD 1929

\*\* The actual tidal period is 12.24 hours. 12 hours was used because it allowed for equal time increments of 0.25 hours. By using 12 hours the velocities could be slightly higher thus making the model tidal period a conservative assumption.

Using the above-defined values, the dynamic boundary condition file was created assuming that the design tide has a sinusoidal shape. Manning's friction coefficient values were developed for varying material types and they varied with depth from the bottom, simulating the change in roughness in the water column due to the presence of vegetation and the boundary layer. Material assignments were utilized to assign proposed elevations, varying Manning's friction coefficients, Smagorinski coefficients, Peclet parameters, as well as eddy viscosities (Table 4 and Figure 4). The ability to manipulate the material properties allows for better represent actual flow conditions. The data ranges for the Manning's friction coefficients can be seen in Table 5 and in Figure 5. When using this method of mesh construction it allows the designer to create contour lines by assigning elevations to the numerical elements, and the designer can group elements into patches of common characteristics (similar roughness parameters, vegetation covers, flooding durations, etc.).

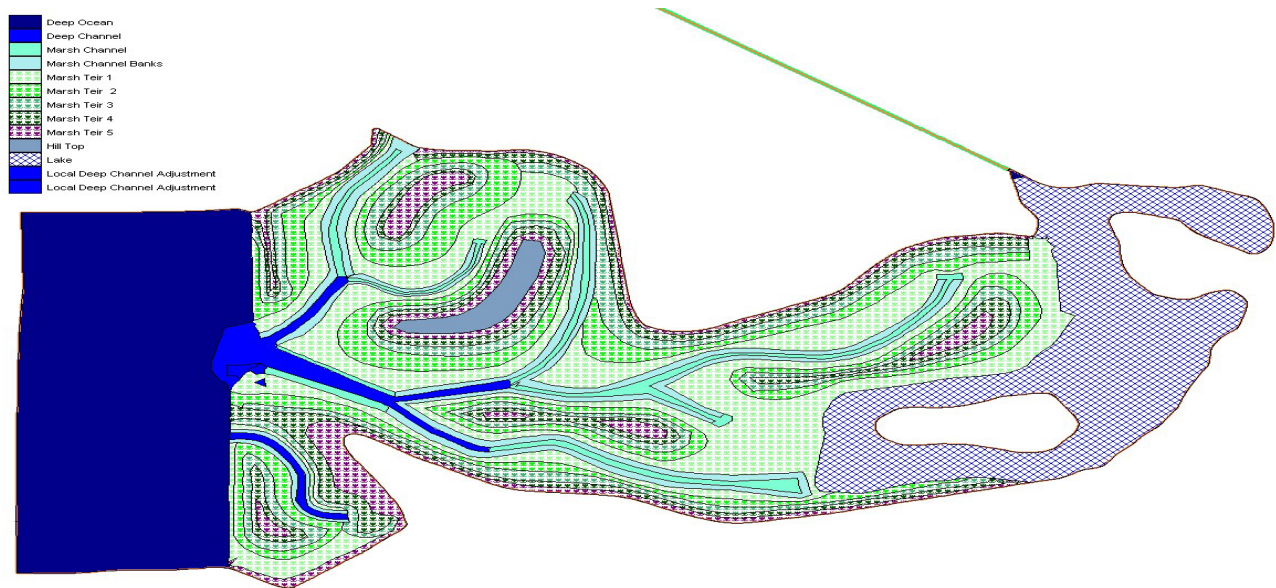


Figure 4: Material Type Assignments

A 1200 ft long, 3ft diameter concrete culvert connected the lake to the river. This flood control structure had to be incorporated into the numerical model. The connection was replicated by one dimensional (depth and width averaged) elements. The “FC Card” feature was utilized to simulate the culvert connection in RMA-2 (USACE, 2001). Reversible flow was assumed, and the relational coefficient was calculated based on the flow through the pipe with 1 ft of head difference between the lake and the pond. The lake end of the culvert had 2.5 ft of silt/muck in it. Thus, the assumed area of the culvert and the hydraulic radius were the average between the culvert nearly full of silt/muck, and a fully open culvert, representative of the river end of the culvert. A Manning’s n value of 0.017 was used, as it was half way between concrete and an unconsolidated channel. Manning’s Equation was used to calculate the flow.

Table 4: Hydrodynamic Modeling Parameters for Lincoln Park RMA2 Model

PARAMETER	VALUES	DEFINITION
Manning's Roughness Coefficient	Varies With Depth	Measures the degree of bed resistance to flow.
Eddy Viscosity (lb-sec/ft <sup>2</sup> )	Varies With Depth	Characterizes the degree of turbulence of the moving flow.
Dynamic Depth Convergence (ft)	0.01	The Maximum allowed change in water depth at any node between two successive iterations is less than the dynamic depth convergence tolerance specified
Time Step (hr)	0.25	The time between two successive solutions.
Marsh Porosity Coefficients	AC1 = 4.5 AC2 = 2.0 AC3 = 0.02	Marsh porosity is an alternate method of wet/dry testing .(See RMA2 Manual)
Smagorinski	TBFACT = 0.5 TBFACT = 0.5 TBMINF = 20.0 TBMINFs = 0.5	Used for complex geometry to assign elements turbulence coefficient by adjusting the eddy viscosity in real time manner. (See RMA2 Manual)
Peclet	GPEC = 20 VPEC = 0.5 EPSXX,EPSXY = 1 EPSYX,EPSYY = 1	The Peclet card allows real-time adjustments to the eddy viscosity based upon the computer average elemental velocity magnitude and individual size of each element.(See RMA2 Manual)

Table 5: Material Properties For Differing Material Types

MATERIAL	MANNING'S ROUGHNESS	EDDY Viscosity
Deep Ocean	0.0095 to .052	20
Deep Marsh Channel	0.0220 to .071	100
Marsh Channel	0.0180 to 0.074	150
Channel Banks	0.0270 to 0.093	200
Base Marsh	0.0300 to 0.100	300
Tier 1,2,3 Banks	0.0330 to .13	300
Tier 4 Bank	0.0500 to 0.850	350
Lake Area	0.0100 to 0.270	100

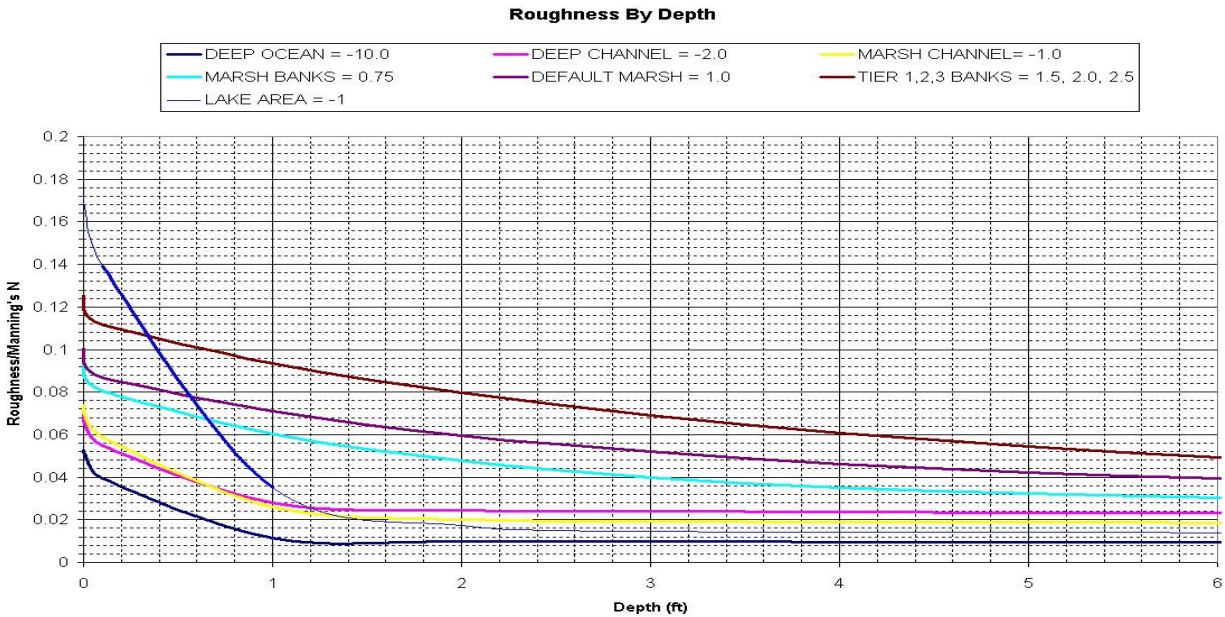


Figure 5: Roughness By Depth For Different Material Types

## Discussion

The study of tidal marshes, such as Lincoln Park, is complicated due to the shallow water conditions, planting criteria, and marsh sensitivity to changing flow conditions. In order to capture and study these complex systems advanced modeling techniques need to be applied. There are many advantages to two-dimensional modeling. In the case of Lincoln Park it allowed us to observe both the changing water elevations and velocities. The obtained information will then allow for manipulation of the tidal creeks and surrounding marsh areas to best match the critical balance of equal deposition and scour of sediment. From early model runs it was apparent that the circulation of the tidal flux through the marsh was not accurate. To address the inaccurate flow Manning's roughness by depth, Marsh Porosity, eddy viscosity, Peclet Turbulence control, and Smagorinski Turbulence controls were used in combination to achieve realistic flow conditions.

The application of Manning's roughness by depth allows the modeler to account for the decrease in roughness as the depth of the water increases. With Lincoln Park the use the varying roughness helps account for the resistance the flow encounters when traveling over and trough the various planting at their assorted stages of growth. By adding Manning's boundary condition we are accounting for the dense planting on and near the surface of the marsh. The input controls of Manning's roughness by depth allow the modeler to establish the minimum and maximum Manning's n values, and the depth of

vegetation. The application of this boundary condition to each of the materials offers a great deal of control over the physical way the tidal flux will flow through Lincoln Park. Roughness by depth alone was not able to produce accurate flow circulation. The next boundary condition applied was eddy viscosity control.

The eddy viscosity parameter reproduces the effects of turbulent diffusion (mixing) by modeling it with friction. For this application it was decided to increase eddy viscosity with each material type to account for the increase in turbulence with height. The eddy viscosity will experience more turbulent conditions in a low flow, which occurs during high tide periods. After several runs using the global eddy viscosity and observing strange flow condition it was decided to make use of the Peclet boundary condition parameter. The Peclet algorithm is used in RMA2 to provide real time adjustments to the eddy viscosity based upon the computed velocity and individual size of each element. The automatic assignment of elemental turbulence coefficients (eddy viscosity) by the Peclet number is a powerful tool. The Peclet algorithm is based on the Peclet number (P) where P is recommended to be between 15 and 40. With in the boundary control conditions there is a variable VPEC (USACE, 2001) that allows the modeler to establish a minimum velocity magnitude used for computation of the Peclet number control. RMA2 uses the VPEC variable as a substitute when the calculated average velocity drops below the modeler specified value. For the Lincoln Park runs a values of  $P = 20$  was used with a VPEC of 0.05 ft/s. The application of the Peclet control did offer substantially improved results but there were still some inaccurate flow conditions occurring in the main marsh channel. It was decide that the use of the Smagorinski parameter could greatly improve flow condition into and out of the main marsh channel. Similar to the Peclet algorithm the Smagorinski algorithm is a real time eddy viscosity calculation that, in our case, allowed RMA2 to calculate the appropriate eddy viscosities and thus show realistic flows.

The hydrodynamic analysis demonstrated that the velocities throughout the site during a tidal cycle are in the range of 0.02 to 2.83 feet per second (fps). The maximum velocities are concentrated within the channels and typically occur just after low tide. Table 6 summarizes the velocities variations for some of the critical channel locations (Figure 6). The results show that the maximum velocities were observed in the main channel, just outside the lake while it was the tide was moving out. This is a section of the main channel, which serves as the primary drainage channel for the Lincoln Park site. The maximum computed velocity in the main channel was approximately 2.83 fps, which just after low tide.

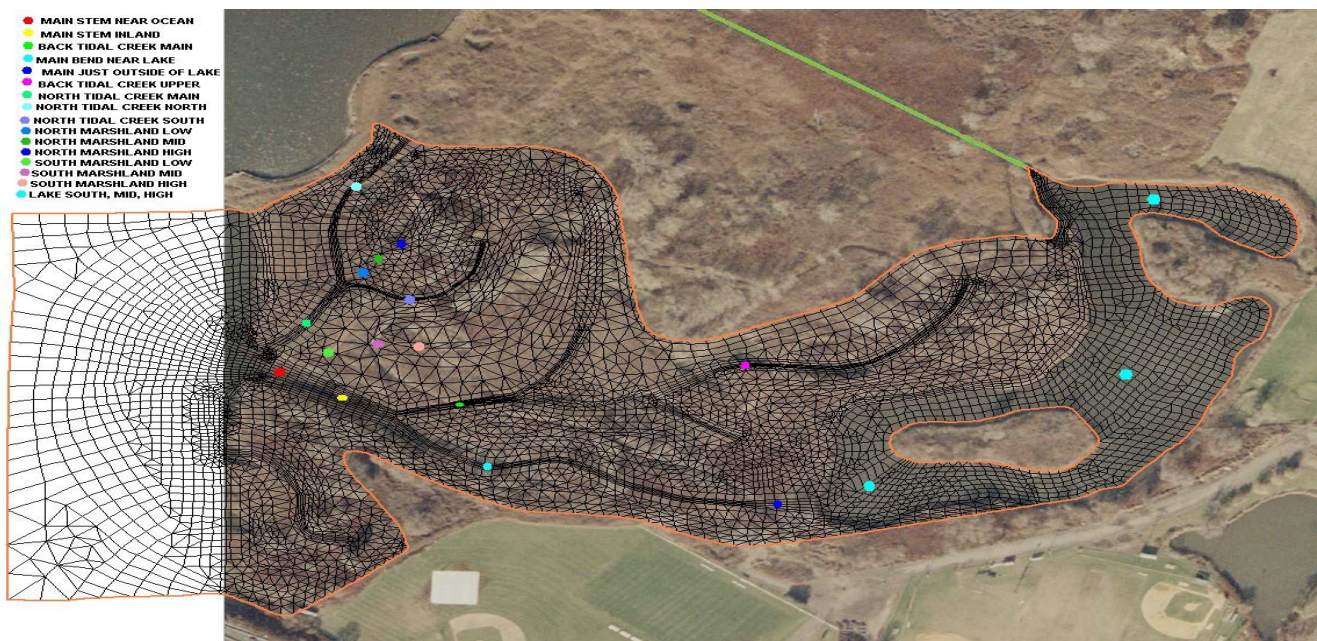


Figure 6: Locations where velocity and water surface elevations are displayed in Table 6 and 7

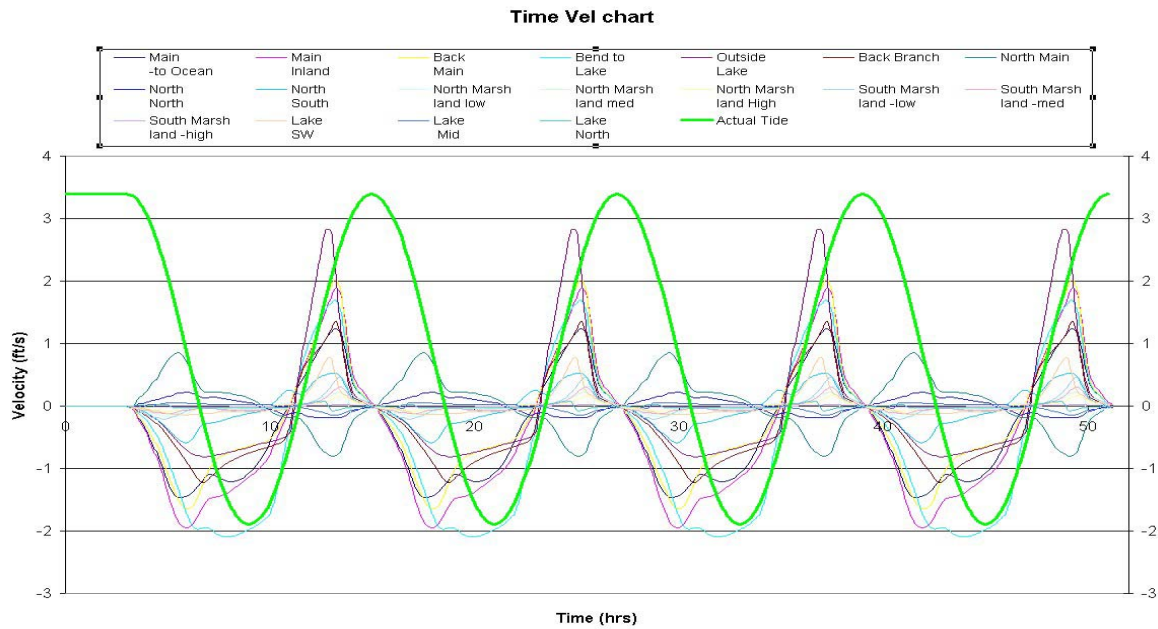


Figure 7: Velocities at Various Locations in the Marsh, Throughout the Tide Cycle

Table 6: Velocities at Various Locations in the Marsh, Throughout One Tide Cycle

Time After High Tide	Main -to Ocean	Main Inland	Back Main	Bend to Lake	Outside Lake	Back Branch	North Main	North North	North South	WSE
0	0.032	0.05	0.022	0.032	0.02	-0.01	-0.01	-0.01	0	3.39
1	-0.418	-0.465	-0.345	-0.238	-0.12	-0.165	0.261	0.063	-0.121	3.04
2	-1.221	-1.392	-1.092	-0.869	-0.401	-0.475	0.734	0.155	-0.376	2.07
3	-1.433	-1.95	-1.64	-1.773	-0.721	-0.929	0.667	0.226	-0.573	0.75
4	-1.098	-1.492	-1.039	-1.943	-0.801	-1.172	0.22	0.133	-0.273	-0.57
5	-1.214	-1.376	-0.745	-2.093	-0.741	-0.895	0.206	0.104	-0.197	-1.54
6	-1.067	-1.134	-0.643	-1.975	-0.66	-0.752	0.125	0.054	-0.121	-1.89
7	-0.556	-0.762	-0.532	-1.705	-0.57	-0.648	-0.081	-0.051	0	-1.54

Time After High Tide	North Marsh land low	North Marsh land med	North Marsh land High	South Marsh land -low	South Marsh land -med	South Marsh land -high	Lake SW	Lake Mid	Lake North	WSE
0	-0.02	0	-0.01	0	-0.014	0	0.032	-0.022	0	3.39
1	-0.094	-0.071	-0.04	-0.14	-0.071	-0.01	-0.032	-0.014	-0.014	3.04
2	-0.17	-0.13	-0.08	-0.199	-0.122	-0.014	-0.114	0.058	0.022	2.07
3	-0.114	-0.081	-0.07	-0.071	-0.06	-0.01	-0.13	0.045	-0.028	0.75
4	-0.045	-0.04	-0.04	-0.041	-0.045	-0.01	-0.112	0.032	-0.032	-0.57
5	-0.067	-0.041	-0.04	-0.071	-0.064	-0.01	-0.098	0.022	-0.03	-1.54
6	-0.054	-0.04	-0.03	-0.086	-0.064	0	-0.081	0.022	-0.03	-1.89
7	-0.02	-0.014	-0.014	-0.036	-0.036	0	-0.067	0.022	-0.03	-1.54

Table 7: Duration of Flooding at Various Locations in the Marsh, Throughout the Tide Cycle

Percent of Time Submerged for Several Location						
	North Marsh land low	North Marsh land med	North Marsh land High	South Marsh land -low	South Marsh land -med	South Marsh land -high
Hours	6.9	6	5.2	6.67	6.5	4.37
Percent of Tide Cycle	58%	50%	43%	56%	54%	36%

The Lincoln Park design allows for a proper tidal inundation and drainage of both the low marsh and high marsh areas as seen in Table 7. Utilizing a tool to graphically show “movies” of the flow as it works its way through the marsh it is apparent that the areas near the lake are draining quickly though the 3-foot tidal flux requirement in the lake does occur.

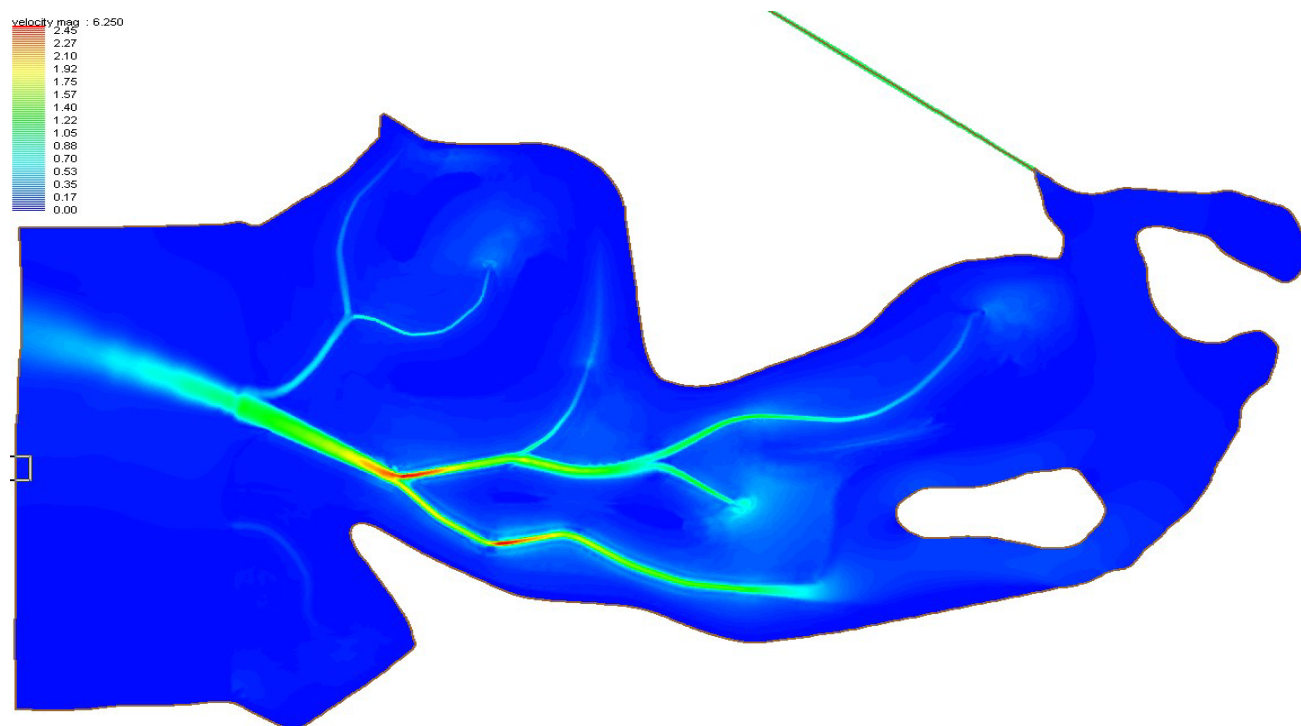


Figure 8: Velocity Results Model at Time Step Hour 44

## Conclusion

The USACE New York District – Engineering Division was presented with the challenge of reintroducing tidal inundation and circulation into a 30-acre area presently dominated by the invasive species, *Phragmites*. The restoration goal of the project was to create as much low marsh, dominated by *S. alterniflora*, as possible. The hydrodynamic model, RMA-2, was employed to validate the creek layout and regrading plan. Over 200,000 cy of material will be excavated to create the chosen alternative, which will put the estimated construction cost for the project above \$5 million. Insuring that the tidal hydrodynamics would facilitate the creation of the 30-acre wetland will dictate the success of the project.

The hydrodynamic analysis for the Lincoln Park –West Project posed many challenges for the team. First, the tide barely penetrated the existing site. Besides a creek that felt the tidal signal only 300 ft inland, and a partially filled in 3 ft culvert, tidal flow had to be predicted over distances 1500 ft inland from the source of the tidal forcing, the Hackensack River. Predicting tidal inundation for that long of a distance using analytical methods would not have been as accurate. Thus a numerical model was needed. Second, evaluating the 1200 ft long culvert, and numerically simulating that flood control structure was also difficult. Third, the low marsh (*spartina alterniflora*) target duration of flooding had to be met everywhere where low marsh was proposed. This was validated by the model results. Lastly, many tools within the RMA-2 code, and within SMS were utilized to adequately portray tidal inundation in the tidal creeks, inlets, lake areas, and the wetland surfaces that experienced wetting and drying every 6 hours. These tools included using 12 different material types, varying roughness, eddy viscosity by material type, Peclet turbulence control, and Smagorinski turbulence control where appropriate. The hydrodynamic model was used to validate the 30 percent design layout, which will be presented in the Ecosystem Restoration Report. Additional tasks in the near future include running a tidal boundary condition that represents the Mean Higher High Water and Mean Lower Low Water tidal datum range.

(6.0 ft), evaluating the locations in the channels where reconfiguration of the channel cross section could lower the ebb velocities so permanent stabilization features (e.g. riprap) could be avoided. A rigorous sensitivity analysis of the model parameters will also be done. In summary, the RMA-2 numerical model has the potential to be an excellent tool to evaluate intertidal wetlands.

### **Acknowledgements**

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